THE USE OF LOCATION AND LOCATION-INTENSITY PATTERNS IN ELECTRO-CUTANEOUS COMMUNICATION

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Section I

1.1 Evaluation of the Katakana Syllabary Codes

On the basis of previous research (semiannual progress report for period 5/1/65 - 10/31/65) four sets of electro-cutaneous stimulus patterns were selected for encoding the Katakana syllabary. Table I presents the Katakana syllabary, while Tables 2a, b, c and d show the assignments of the syllabary characters to the various points available for stimulation. Figures Ia, b, c and d illustrate the locations on the hands which are used in each code. In the Tables, R=right hand, L=left hand, and the numbers refer to the locations given in Figures Ia, b c and d. Thus, for code #3, RI indicates that the right little finger-tip is stimulated and this corresponds to the Katakana character "A" (a vowell sound). The code symbols: L5RI mean that the left thumb-tip and right little finger-tip are stimulated simultaneously and represent the syllabary sound "KA". Finally, and again in Table 2c (code 3), the code designation: L12-5 RI refers to the simultaneous stimulation of the base of the left palm and thumb-tip, and the tip of the little finger on the right hand and designates the "GA" character. The other codes are similarly interpreted.

In Figures Ia, b, c and d, the circled locations indicate the points used in each code up to the time of this report. Thus, again for code 3, positions RI, R2, R3, R4, R5, L5 and L4 have been used to date. It is from the information obtained through the use of the points circled in each figure that the data presented below were computed.

1.2 Subjects: Eight Japanese Ss were obtained and two were assigned to each code. Because of the scarcity of the supply of Japanese Ss, it was not possible to exercise selectivity to any meaningfull extent. Consequently both slow and rapid learners were obtained. Of the pairs worked with to date, two (used with codes 1 and 3) have had one rapid and one slow learner , while the members of the third pair (used with code 4) have been about equal in their performance. Five of the six Ss employed so far have been females. The one male and his spouse have worked on code 3.

1.3 Apparatus: An electro-mechanical system capable of delivering patterns of brief, dc stimuli to palm and fingertip locations has been used. This apparatus has been described previously (Foulke, 1965). Briefly, a system of relays, controlled by an eight-hole tape reader, or by a manual operation, distributes the output of a dc power supply to three terminals on a plug board. From the plug board the signals are distributed to S's stimulating electrodes by means of patch-plugs prewired for each code. Thus, each code employed in the training session was selected by inserting the appropriate patch-plug into the plugboard.

Each S is furnished clay molds of his or her right and left hands. Stainless steel electrodes are embedded in the ceramic clay molds. Passive electrodes are attached to S's right and left arms. A variable resistance is connected in series with the lead to each active electrode so that S can adjust the intensity of stimulation at any location according to his own preference. In addition,a master potentiometer, connected in series with the return lead, allows simultaneous adjustment of the intensity at all of the electrodes.

1.4 Procedure: Training was pursued using a paired-associates technique. Ss were cued as to what signal was to be sent, then the signal was sent, and S repeated the symbol represented by the signal. An attempt was made to present the training in a manner that would reduce the likelihood of errors on Ss part. Accordingly, S was first presented, in serial order, the symbols in the particular column of the Katakana syllabary being used (see Table I for a designation of the columns I through 10). S was cued before the presentation of the signal. Following two presentations of the symbols in a column in a cued and conventionally ordered sequence, Ss were sent the same columnar symbols ten times, but this time the order of presentation was randomly permuted, add S was cued as before. Following the presentation of the cued, randomly presented signals, S was tested to see how well he had learned to associate the Katakana characters of the column being worked on with the electrical stimulation patterns. The test consisted of the random, uncued presentation of the five characters in the column for ten times apiece, while S attempted to identify the signal being sent. Since there were five characters which were sent ten times, there were fifty signals sent in one test trial. S was given a number of trials to reach a criterion (which, because of the ability differences between Ss, was varied for individual Ss) of correct identifications of the signals.

After learning the first column of characters, training as described above was given on column two. Following this, Ss were asked to identify words constructed from the symbols in columns one and two.

Thirty-eight words were constructed and presented. One time through the list was considered a trial. Again, a number of trials were given until Ss reached a satisfactory criterion of correct identifications of the words. Following attainment of the criterion level of performance on the words from columns one and two, Ss were trained on column three. Then they were tested on identifying words constructed of symbols from columns one, two and three. In this case, there were fifty words in each trial. Again, it should be mentioned that due to several factors, it was necessary to set different criterion levels for different Ss. These factors involved individual differences in ability, differences in the difficulty of the codes, and morale. The latter was important because a S was likely to become upset if he thought that he was not doing as well as his partner. Thus Ss were at times advanced to the next stage of training along with their partners (or shortly thereafter) without having reached a similar level of performance on the preceeding training task.

In evaluating the codes, we have used the first five trials of the word tests for columns one and two and for columns one, two and three. Some Ss took longer than five trials to learn their lists and some never learned them completely. But others had mastered the lists in five trials, so it is felt that ease in learning the word lists during the first five trials accurately reflects differences in the codes.

Confusion matrices have been constructed for each S for the first three columns. These matrices allow us to determine the percent correct identifications of the signals sent, and to examine which stimulation points produced most incorrect identifications, i.e., which were most confused with others. The results presented below pertain to codes one, three and four. Code two has not been evaluated yet.

1.5 Results: Figures 2a - f present confusion matrices for each S. Figures 2a and b are for code 1; figures 2c and d are for code 3; and figures 2e and f are for code 4. Directly below each matrix are given the percent correct identifications of the signals. The column labeled "?" means that the S responded with "I don't know". Summing all the percentages for each matrix and taking the mean gives an indication of the mean correct identifications for the first three columns for each S. By adding the latter figures for both Ss on each code, and dividing by two, the overall mean percent of correct identifications for that code is obtained. These data are presented for each code in Figure 3. It is seen that, in general, code 3 produced about 10% more correct identifications than either of codes 1 or 4.

Figure 4 presents the combined mean percent correct identifications of the words constructed from columns 1 and 2 for both Ss for each code for each of the first five trials. It is apparent that code 3 is superior to codes 1 and 4 both in performance on trial 1 and on trial 5.

Figure 5 presents the combined mean percent correct identifications of the words constructed from columns one, two and three for both Ss for each code for each of the first five trials. Again it is obvious that code 3 is superior, although performance on code 1 is still improving at trial 5. The results for trial 8 given in figure 5 are for one S on each of codes one and three. Both Ss were the slow learners. The figure indicates that both Ss on both codes are doing about equally well at trial 8. Both were about asymptotic in fact at trial 8. These results indicate how the performance of the poor learner tended to attenuate the mean percent correct score. But since there was a fast and slow learner for both codes one and three, while code 4 had two average learners, the means pictured in the figures give a good indication of the performance of an average learner on each code.

By reference to the confusion matrices and to figures 1a, b and c it is possible to determine which stimulus locations in each code produced confusion. With code 1, subject L confused "I", "U" and "E" in column one. From Table 2a we see that "I" = R10, "U" = R11 and "E" = R12, all palmar positions. In column two, subject L confused "KI", "KU" and "KE" most frequently. The points stimulated for these symbols are "KI" = R2-10, "KU" = R2-11 and "KE" = R2-12. Again palmar positions are confused. With the third column, subject L confused "SI" and "SU" with "SE", and again these correspond to the palmar locations. Subject H did poorly on only three sumbols in the first three columns of code 1. She confused "I" with "A" (i.e., R10 with R1), "SE" with "SO" (R3-12 with R3-6), and "KI" with "KU" (R2-10 with R2-1). Thus her greatest trouble was discriminating R1 (right little finger-tip) from R10 (base of right little finger). The latter discrimination has proved difficult for most Ss.

Similar analyses as above, with codes three and four, permit the general statement of results that palmar locations tend to produce systematic confusion whereas little systematic confusion was found with fingertip stimulation, as in code three.

1.6 Discussion: On the basis of the results presented above, training on codes one and four has been discontinued. Our conclusion is that for the most effective codes, palmar positions must be avoided. We shall be able to test this conclusion when training on code two begins. For the first three columns in code two, stimulation is limited to the fingertips. The stimulus locations are, in fact, identical to those used in code three. We expect to find, therefore, that the learning curves for code two resemble those for code three. However, since code two involves more palmar locations than code three does, as the codes proceed beyond the first three columns of the syllabary, we expect that code three shall ultimately prove superior to code two.

1.7 Current Status: *S*s released from training on codes one and four are being reassigned to codes three and two. In addition, two new *S*s are being given training on code two. It is anticipated that the results obtained with these two codes will enable us to devise an optimal code. Attention will then turn toward ascertaining the upper limits of code reception using the Katakana syllabary.

Dr. Robert Gibson, at the University of Pittsburgh, was invited to visit the project as a consultant. After discussing our electro-cutaneous codes with him, it was concluded that a better choice of signals could have been made. In accordance with his suggestion, we plan to replace the present dc pulses with 1000 cps sinusoidal signals of approximately 20 msec. duration. The apparatus required to accomplish this change is now under construction.

TABLE Ia
THE KATAKANA SYLLABARY

5			4		3		2	1	
HA	(PA)	(BA)	TA	(DA)	SA	(ZA)	KA	(GA)*	A
HI	(PI)	(BI)	TI	(DI)	SI	(ZI)	KI	(GI)	I
HU	(PU)	(BU)	TU	(DU)	SU	(ZU)	KU	(GU)	U
HE	(PE)	(BE)	TE	(DE)	SE	(ZE)	KE	(GE)	E
HO	(PO)	(BO)	TO	(DO)	SO	(ZO)	KO	(GO)	O

10	9	8	7	6
WN	WA	LA	YA	MA
	I	LI	YI	MI
	U	LU	YU	MU
	E	LE	YE	ME
	O	LO	YO	MO

*Symbols in parentheses are alternate sounds for the symbols in the column following (reading right to left) the parentheses.

TABLE 2a
ELECTRO-CUTANEOUS COMMUNICATION
KATAKANA SYLLABARY
CODE #1

A	R1
*I	R10
*U	R11
*E	R12
*O	R 6
KA	R 2-1
KI	R 2-10
KU	R 2-11
KE	R 2-12
KO	R 2-6
SA	R 3-1
SI	R 3-10
SU	R 3-11
SE	R 3-12
SO	R 3-6
TA	R 4-1
TI	R 4-10
TU	R 4-11
TE	R 4-12
TO	R 4-6
NA	R 5-1
NI	R 5-10
NU	R 5-11
NE	R 5-12
NO	R 5-6
HA	L5R1
HI	L5R10
HU	L5R11
HE	L5R12

MA	L4R1	
MI	L4R10	
MU	L4R11	
ME	L4R12	
MO	L4R6	
YA	L3R1	
*I	R10	
YU	L3R11	
*E	R12	
YO	L3R6	
LA	L2R1	
LI	L2R10	
LU	L2R11	
LE	L2R12	
LO	L2R6	
WA	L1R1	
*I	R10	
*U	R11	
*E	R12	
*O	R6	
WN	L1	
GA	L12	R2-1
GI	L12	R2-10
GU	L12	R2-11
GE	L12	R2-12
GO	L12	R2-6
ZA	L12	R1-3
*(DI)ZI	L12	R3-10
*(DU)ZU	L12	
ZE		

DA	L12	R4-1
*(ZI)DI	L12	R4-1
*(ZU)DU	L12	R4-11
DE	L12	R4-12
DO	L12	R4-6
BA	L12-5	R1
BI	L12-5	R10
BU	L12-5	R11
BE	L12-5	R12
BO	L12-5	R6
PA	L6	R1
PI	L6	R10
PU	L6	R11
PE	L6	R12
PO	L6	R6
。	L5	
,	L4	
I	L3	
<	L2	

*Also appears elsewhere

TABLE 2b
ELECTRO-CUTANEOUS COMMUNICATION
KATAKANA SYLLABARY
CODE #2

A	R1
*I	R2
*U	R3
*E	R4
*O	R5
KA	L5R1
KI	L5R2
KU	L5R3
KE	L5R4
KO	L5R5
SA	L4R1
SI	L4R2
SU	L4R3
SE	L4R4
SO	L4R5
TA	L3R1
(CHI)TI	L3R2
(TSU)TU	L3R3
TE	L3R4
TO	L3R5
NA	L2R1
NI	L2R2
NU	L2R3
NE	L2R4
NO	L2R5
HA	L1R1
HI	L1R2
HU	L1R3

MA	L6	R1
MI	L6	R2
MU	L6	R3
ME	L6	R4
MO	L6	R5
YA	L7	R1
*I		R2
YU	L7	R3
*E		R4
YO	L7	R5
LA	L8	R1
LI	L8	R2
LU	L8	R3
LE	L8	R4
LO	L8	R5
WA	L9	R1
*I		R2
*U		R3
*E		R4
*O		R5
WN	L9	
GA	L12-5	R1
GI	L12-5	R2
GU	L12-5	R3
GE	L12-5	R4
GO	L12-5	R5
ZA	L12-4	R1
*(DI)ZI	L12-4	R2
*(DU)ZU	L12-4	R3
ZE		R4
ZO		R5

DA	L12-3	R1
*DI	L12-3	R2
*(ZU)DU	L12-3	R3
DE	L12-3	R4
DO	L12-3	R5
BA	L12-1	R1
BI	L12-1	R2
BU	L12-1	R3
BE	L12-1	R4
BO	L12-1	R5
PA	L10	R1
PI	L10	R2
PU	L10	R3
PE	L10	R4
PO	L10	R5
.	L5	
,	L4	
!	L3	
<	L2	

*Also appears elsewhere

TABLE 2c
ELECTRO-CUTANEOUS COMMUNICATION
KATAKANA SYLLABARY
CODE #3

A	R1
*I	R2
*U	R3
*E	R4
*O	R5
KA	L5R1
KI	L5R2
KU	L5R3
KE	L5R4
KO	L5R5
SA	L4R1
SI	L4R2
SU	L4R3
SE	L4R4
SO	L4R5
TA	L3R1
(CHI)TI	L3R2
TU	L3R3
TE	L3R4
TO	L3R5
NA	L2R1
NI	L2R2
NU	L2R3
NE	L2R4
NO	L2R5
HA	L1R1
HI	L1R2
HU	L1R3
HE	L1R4
HO	L1R5

MA	L4-5	R1
MI	L4-5	R2
MU	L4-5	R3
ME	L4-5	R4
MO	L4-5	R5
YA	L3-5	R1
*I		R2
YU	L3-5	R3
*E		R4
YO	L2-5	R5
LA	L2-5	R1
LI	L2-5	R2
LU	L2-5	R3
LE	L2-5	R4
LO	L1-5	R5
WA		R1
*I		R2
*U		R3
*E		R4
*O		R5
WN		R12
GA	L12-5	R1
GI	L12-5	R2
GU	L12-5	R3
GE	L12-5	R4
GO	L12-5	R5
ZA	L12-4	R1
*(DI)ZI	L12-4	R2
*(DU)ZU	L12-4	R3
ZE	L12-4	R4
ZO	L12-4	R5

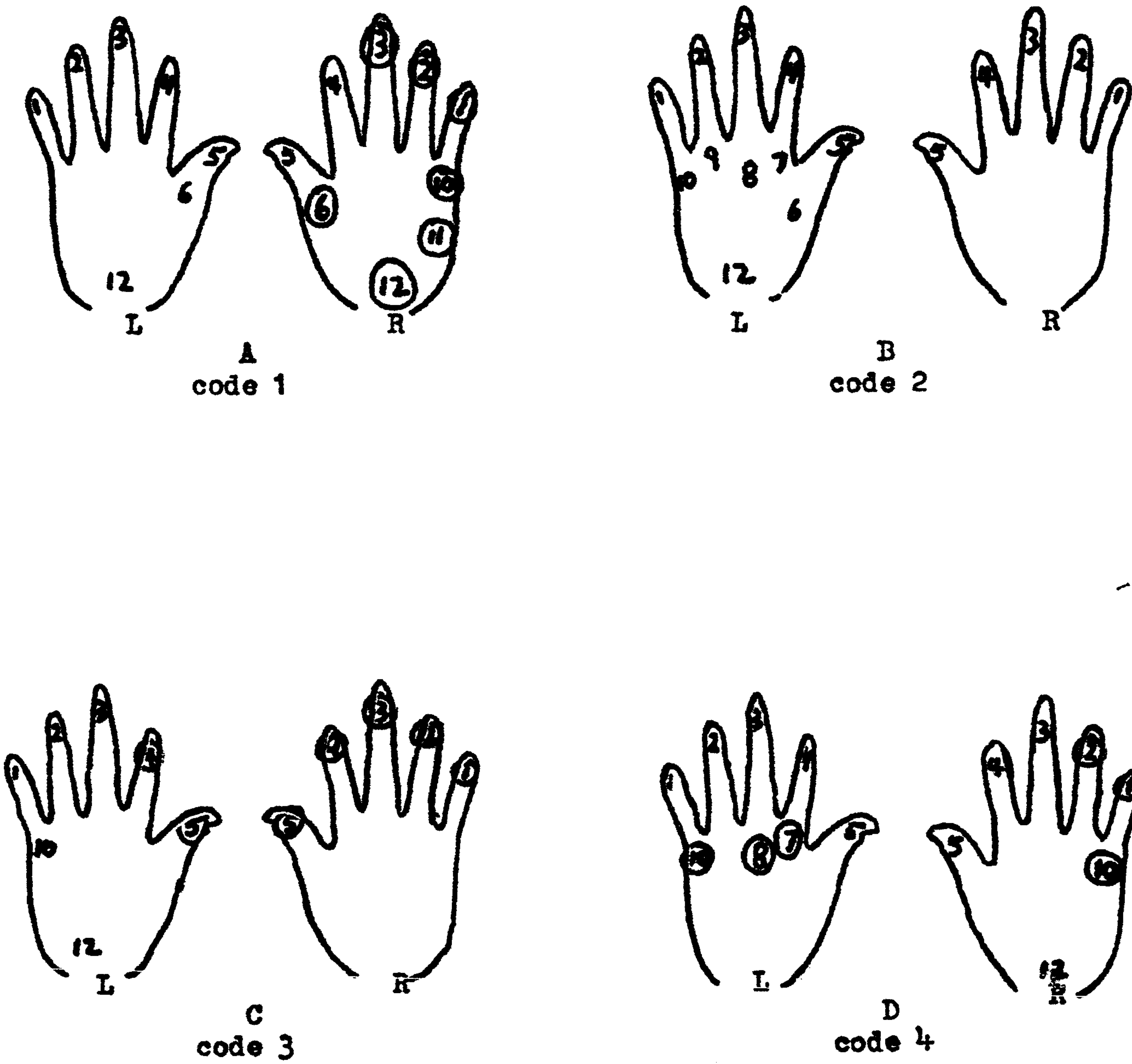
DA	L12-3	R1
*(ZI)DI	L12-3	R2
*(ZU)DU	L12-3	R3
DE	L12-3	R4
DO	L12-3	R5
BA	L12-1	R1
BI	L12-1	R2
BU	L12-1	R3
BE	L12-1	R4
BO	L12-1	R5
PA	L10	R1
PI	L10	R2
PU	L10	R3
PE	L10	R4
PO	L10	R5
、	L5	
。	L4	
|	L3	
∠	L2	

*Also appears elsewhere

TABLE 2d
ELECTRO-CUTANEOUS COMMUNICATION
KATAKANA SYLLABARY
CODE #4

A	R10	
*I	R7	
*U	L7	
*E	L8	
*O	L10	
KA	R1-10	
KI	R1-7	
KU	R1L7	
KE	R1L8	
KO	R1L10	
SA	R2-10	
SI	R2-7	
SU	R2L7	
SE	R2L8	
SO	R2L10	
TA	R3-10	
(CHI)TI	R3-7	
TU	R3L7	
TE	R3L8	
TO	R3L10	
NA	R4-10	
NI	R4-7	
NU	R4L7	
NE	R4L8	
NO	R4L10	
HA	R5-10	
HI	R5-7	
HU	R5L7	
HE	R5L8	
HO	R5L10	
MA	L5	R10
MI	L5	R7
MU	L5-7	
ME	L5-8	
MO	L5-10	
YA	L4	R10
*I		R7
YU	L4-7	
*E	L8	
YO	L4-10	
LA	L3	R10
LI	L3	R7
LU	L3-7	
LE	L3-8	
LO	L3-10	
WA	L2	R10
*I		R7
*U	L7	
*E	L8	
*O	L10	
WN	L2	
GA	L1	R1-10
GI	L1	R1-7
GU	L1-7	R1
GE	L1-8	R1
GO	L1-10	R1
ZA	L1	R2-10
*(DI)ZI	L1	R12-7
*(DU)ZU	L1-7	R2
ZO	L1-8	R2
DA	L1	R3-10
*(ZI)DI	L1	R3-7
DU	L1-7	R3
DE	L1-8	R3
DO	L1-10	R3
BA	L1	R5-10
BI	L1	R5-7
BU	L1-7	R5
BE	L1-8	R5
BO	L1-10	R5
PA		R6-10
PI		R6-7
PU	L7	R6
PE	L8	R6
PO	L10	R6
,	L5	
,	L4	
!	L3	
<	L1	

*Also appears elsewhere



Figures 1a,b,c,d

Stimulus locations used for each of the Katakana codes.

Figure 2a

Code I
Subject L

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		A	I	U	E	O	KA	KI	KU	KE	KO	SA	SI	SU	SE	SO	?
	A	91	14	4	1												
	I	15	59	18	18												
N=110	U	6	8	74	21												1
	E	2	9	34	65												
	O				1	109											
	KA						80	2	5	3							
SENT	KI				1		14	53	14	7	1						
	KU		4				3	16	60	7							
N=90	KE		1				1	2	18	68							
	KO									1	89						
	SA											35	4	1			
	SI											4	25	2	7	2	
N=40	SU												1	26	13		
	SE												2	3	32	3	
	SO													1	1	38	
% Correct		83	54	67	59	99	89	59	67	76	99	88	63	65	80	95	

Figure 2b

Code I
Subject H

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		A	I	U	E	O	KA	KI	KU	KE	KO	SA	SI	SU	SE	SO	?
	A	78	22														
	I	13	84	3													
N=100	U		3	97													
	E				97	1											2
	O				1	99											
	KA						94	5		1							
SENT	KI						19	79	2	7							
	KU								98	2							
N=100	KE							3		96	1						
	KO						1				99						
	SA											18	1		1		
	SI												18		1	1	
N=20	SU													18		2	
	SE														16	4	
	SO															20	
% Correct		78	84	97	97	99	94	79	98	96	99	90	90	90	80	100	

78 22

Figure 2c

Code III
Subject SC

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		A	I	U	E	O	KA	KI	KU	KE	KO	SA	SI	SU	SE	SO	?
	A	10															
	I		10														
N=10	U			10													
	E				10												
	O					10											
	KA						30										
SENT	KI							30									
N=30	KU								25	5							
	KE							1	4	25							
	KO							1	2	1	26						
	SA											10					
	SI												10				
N=10	SU													10			
	SE														10		
	SO															10	
% Correct		100	100	100	100	100	100	100	83	83	87	100	100	100	100	100	

Figure 2d

Code III
Subject MC

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		A	I	U	E	O	KA	KI	KU	KE	KO	SA	SI	SU	SE	SO	?
	A	75			1												4
	I	1	73														6
N=80	U			76													4
	E	1			75												4
	O					78											2
	KA						66	2									2
	KI							67									3
SENT	KU								62								8
N=70	KE								2	68							
	KO										70						
	SA											77			2	1	
	SI											2	76	2			
N=80	SU													73	7		
	SE											1		2	77		
	SO														1	79	
% Correct		94	91	95	94	98	94	96	89	97	100	96	95	91	96	99	

Figure 2e

Code IV
Subject Z

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		A	I	U	E	O	KA	KI	KU	KE	KO	SA	SI	SU	SE	SO	?
	A	30															
	I		29			1											
N=30	U			23	7												
	E		2	9	18												1
	O					30											
SENT	KA						29	1									
	KI						3	27									
N=30	KU							2	28								
	KE								5	24	1						
	KO							1			29						
	SA											18	2				
	SI											7	13				
N=20	SU													19	1		
	SE													3	16	1	
	SO															20	
% Correct		100	93	77	60	100	97	90	93	80	97	90	65	95	80	100	

Figure 2f

Code IV
Subject S

RECEIVED

		A	I	U	E	O	KA	KI	KU	KE	KO	SA	SI	SU	SE	SO	?
	A	30															
	I		29														1
N=30	U			24	6												
	E			3	27												
	O					30											
SENT	KA						56	4									
	KI						15	45									
N=60	KU						2		45	12	1						
	KE						1	1	9	49							
	KO							1	4	1	54						
	SA											17	2		1		
	SI											3	17				
N=20	SU													14	5	1	
	SE													3	16	1	
	SO											1		2	1	15	1
% Correct		100	97	80	90	100	93	75	75	82	90	85	85	70	80	75	

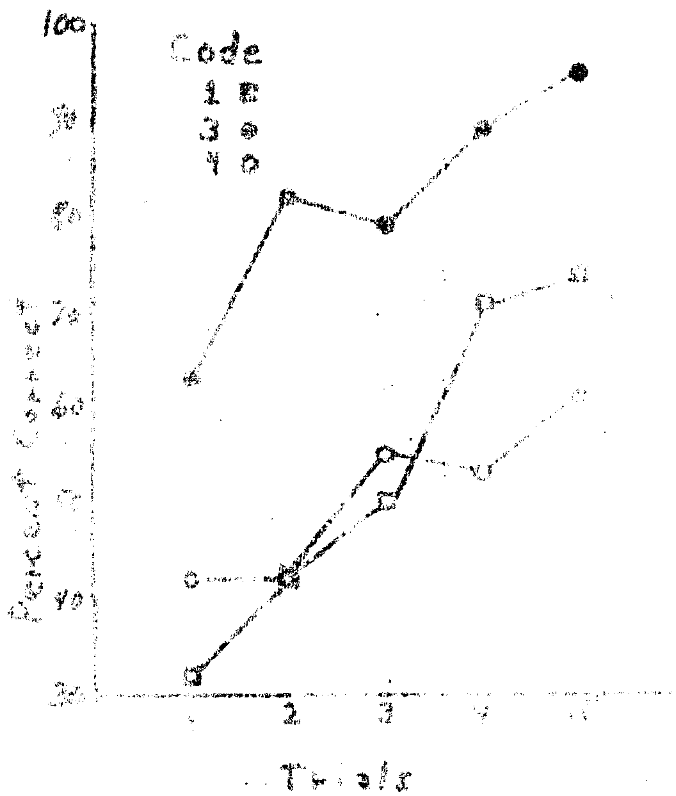
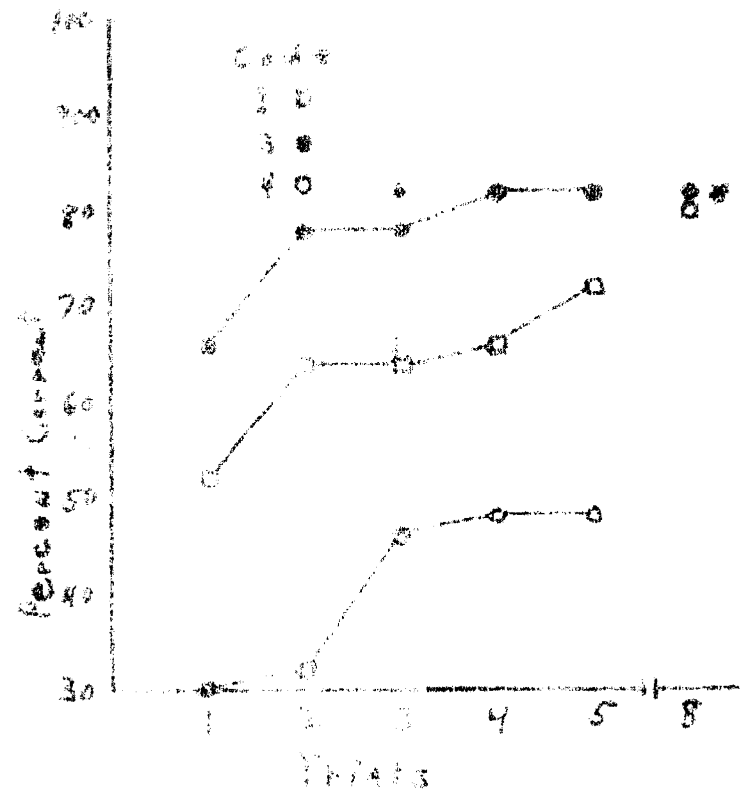


Figure 4. Learning curves for words formed by [illegible] the first two columns of [illegible] Katakana syllabary, [illegible] words per trial).



[illegible] 5. Learning curves for words formed [illegible] of the first three columns [illegible] syllabary ([illegible])
[illegible]

Section II

2.0 Reaction Time to Electrocutaneous Onset and Offset Stimulation as a Function of Rise and Decay Time.

Recently (1,2) we substantiated a previous finding by Woodrow (3) that the reaction time (RT) to the cessation of an AC electrocutaneous stimulus is longer than the RT to the onset of the stimulus. We have found this relation to hold for intensities ranging from 400-700 μA and for frequencies of 70-500 cps when the current is held constant for each frequency.

To explain the differences in response latencies to onset-offset stimuli, we have appealed to the phenomenon of adaptation of nerve and sense organs, as discussed by Adrian (4), in which there is a rapid increase in the frequency of neural impulses upon stimulation, and then a gradual decline in the frequency with continued application of the stimulus. It has in fact been demonstrated (5) that adaptation to AC stimuli occurs with human subjects and that there is a rapid initial adaption following the onset of the current, followed by a relatively slow period of adaptation in which the intensity of the sensation slowly declines. To account for the onset-offset RT differences, we suggested (2) that with the onset of the current there is an initial high frequency "burst" of impulses which signals the stimulus onset. However, due to adaptation, the number of impulses decreases rapidly and thus the change in neural input at the offset of the stimulus is less than that produced by the onset, and this difference is indexed by the increase in response latency following the stimulus offset.

In the study reported herein, we have tested the foregoing hypothesis by the use of five different rise and decay times: 0.5, 5, 25, 100 and 250 msec. Thus, with the fast rise times we expected to confirm that onset RT's were faster than offset RT's, while with the longer rise times, which would avoid an initial "burst" of impulses, it was expected that there would be no differences between onset and offset RT's. As indicated below, the latter expectation proved only partially correct.

Presentation of the stimuli was accomplished by means of a Grayson-Stadler model 829D electronic switch which permitted the selection of the rise and decay times. The electronic switch controlled a 70 cps signal provided by a Hewlett-Packard model 201CR audio oscillator coupled to the switch through a Daven Company, type 7717 attenuator which permitted one db increment or decrement in the oscillator output. The output of the electronic switch was coupled to a 75 watt McIntosh audio amplifier which was matched to S's impedance by a United type LS-12 transformer. A 200K-ohm resistance was connected in series with the subject to limit changes in stimulus current due to fluctuations in the subject's resistance. Stimulus current was determined with a Ballantine model 200E AC voltmeter by measuring the voltage drop across a 100 ohm precision resistor in series with the subject. Stimulus intensity was adjusted by reference to the voltmeter. Stimulus foreperiods were controlled with a Hunter model 100B timer connected to the external control circuit of the electronic switch.

Reaction times were measured with a Hunter Klockounter.

In the onset condition, the stimulus was delivered at the end of the foreperiod, and the subject reacted to the appearance of the signal. In the offset condition, the signal came on at the beginning of the foreperiod and went off at the end of the foreperiod, and the subject reacted to the cessation of the stimulus. The duration of the foreperiod was varied randomly within a 2-4 sec. interval to preclude synchronization of responses by the subject. The latter was seated in a IAC model 400 sound deadened booth. The subject's left hand rested on a board containing a 3 1/2 inch inactive electrode which covered the breadth of the hand. The active electrode was a circular stainless steel disc (5/8 inch in diameter) on which the first phalange of subject's left index finger rested. With his right hand, the subject held a telegraph key closed. The latter was placed in series with the Hunter timer and Klockounter such that when the stimulus was delivered, at the end of the foreperiod, the Klockounter started counting time, and stopped when the subject released the telegraph key - which he was instructed to do immediately upon detecting the stimulus. The RT was then recorded from the Klockounter.

All of the five rise and decay times mentioned above were used with each of five intensity levels. The envelopes of these combinations were checked with a Hewlett-Packard model 120 AR oscilloscope and found to be linear. The intensities used varied among subjects, since it was desirable to cover a full range of intensities from near threshold to strong, and each subject's threshold was different. The intensities for each subject were: EP = 338, 400, 500, 640 and 800 μA; LM = 426, 550, 881, 1133 μA; RH = 340, 400, 520, 700 and 900 μA. To obtain these intensities, ascending thresholds were obtained during five practice hours and stimuli 2, 4, 6, 8 and 10 db above the threshold were used. Actually, due to changes in sensitivity occurring during the 10 experimental days it was necessary to increase the weakest intensity at times and so the intensities given are the mean intensities for the 10 days. However, there was never more than a 20 μA adjustment required. The three, male, student subjects received 1000 practice responses prior to the experiment. During the experiment, four offset RTs were obtained for each decay time x intensity combination, and then four onset RTs were taken for the corresponding rise time x intensity combination. This order was reversed from day to day. Also, the presentation of stimulus combinations was counterbalanced to preclude order effects. A total of 40 onset and offset RTs per stimulus combination were obtained.

The means and standard deviations for all conditions were computed for each subject. A plot of the means for each subject is presented in figure ~~one~~ 2.1a, b, c against log μA/msec, the rate of current increase or decrease per msec., on the abscissa. Several features of these curves are noticeable: (1) with low rates of current increase or decrease, the offset RTs are <u>faster</u> than the onset RTs, while with the faster rates of current increment or decrement, the offset RTs are <u>slower</u> than the onset RTs; (2) for all three subjects, the point at which the offset RTs switch from being consistently slower than onset RTs, to being faster, lies between a rate of current flow of 8-11 μ A/ msec; (3) there are rapid fluctuations of onset and offset RTs with rates between 0.5-0.8 log μ A/msec; and (4) the recurrent "humps" in the curves indicate that RT is not solely determined by the rate at which current is applied. It is also dependent upon the peak current delivered. Thus, for subject EP, it is seen that the onset and offset RTs obtained with 2.0 log μ A/msec. rate are faster than those obtained with 2.8 log μ A/msec. The former rate was obtained by dividing the peak current of 500 μ A by the 5 msec. rise time, giving a 100 μ A/msec. rate of current increase. The 2.8 log μ A/msec. rate was computed by dividing 338 μ A by 0.5 msec., which gives a faster rate but which has a lower peak intensity. Thus there is a degree of reciprocity between intensity (peak μ A) and rise-decay time with respect to RT such that RTs may be reduced by applying a low intensity stimulus rapidly, or a high intensity stimulus slowly. However, this relation disappears with rates below 10 μ A/msec., which corresponds to the point where offset and onset RTs reverse their relative positions. The offset RT is affected much more than the onset RT by the peak intensity.

The foregoing offers support for the contention that the difference between onset and offset RTs observed previously (1, 2, 3) may be attributed to differences in the amount of change in neural activity following rapid onsets or offsets of the electric stimulus. With slow rates of current flow the onset stimulation may be attenuated to the extent that the offset RTs become faster than the onset RTs. In fact, our data show that, with each of the five intensities used, the offset RTs are longer than the onset RTs with rise-decay times of 25 msec. or below. With rise times over 25 msec. in duration, there is an interaction between intensity and rise-decay time such that offset RTs become faster than onset RTs and the greater the intensity the sooner does this reversal occur. Figure ~~2~~ 2.2 presents the RTs for subject LM for three intensity levels plotted against the rise-decay times <u>between</u> which the relative positions of the onset and offset RTs are exchanged. By dropping a perpendicular from the decussation point of the onset-offset curve for a given intensity to the abscissa, one can determine the rise-decay time for that intensity which produces equal onset and offset RTs. This procedure is illustrated in figure 2.2. We have called this point the "decussation time". Figure ~~3~~ 2.3 presents a plot of decussation time against intensity on the abscissa for each subject. Thus it is seen that the decussation time decreases as intensity increases (with RH showing some deviation). Presumably the decussation time represents the rate of increase in neural impulse input which produces as discriminable a change as that produced by a reduction in input with the cessation of stimulation.

It is felt that decussation time may prove a usefull index in psychophysical and electrophysiological studies involving electrocutaneous stimulation. For instance, if it is assumed that the increase in both onset and offset RTs, when slow rates of current flow are used, is due to an accommodation of rapidly conducting fibers, then it ought to be possible to demonstrate the onset-offset decussation effect by ischemia, which has been shown to produce a decrease in latency and amplitude of the nerve action potentials evoked by stimulation of the ulnar nerve in man (6).

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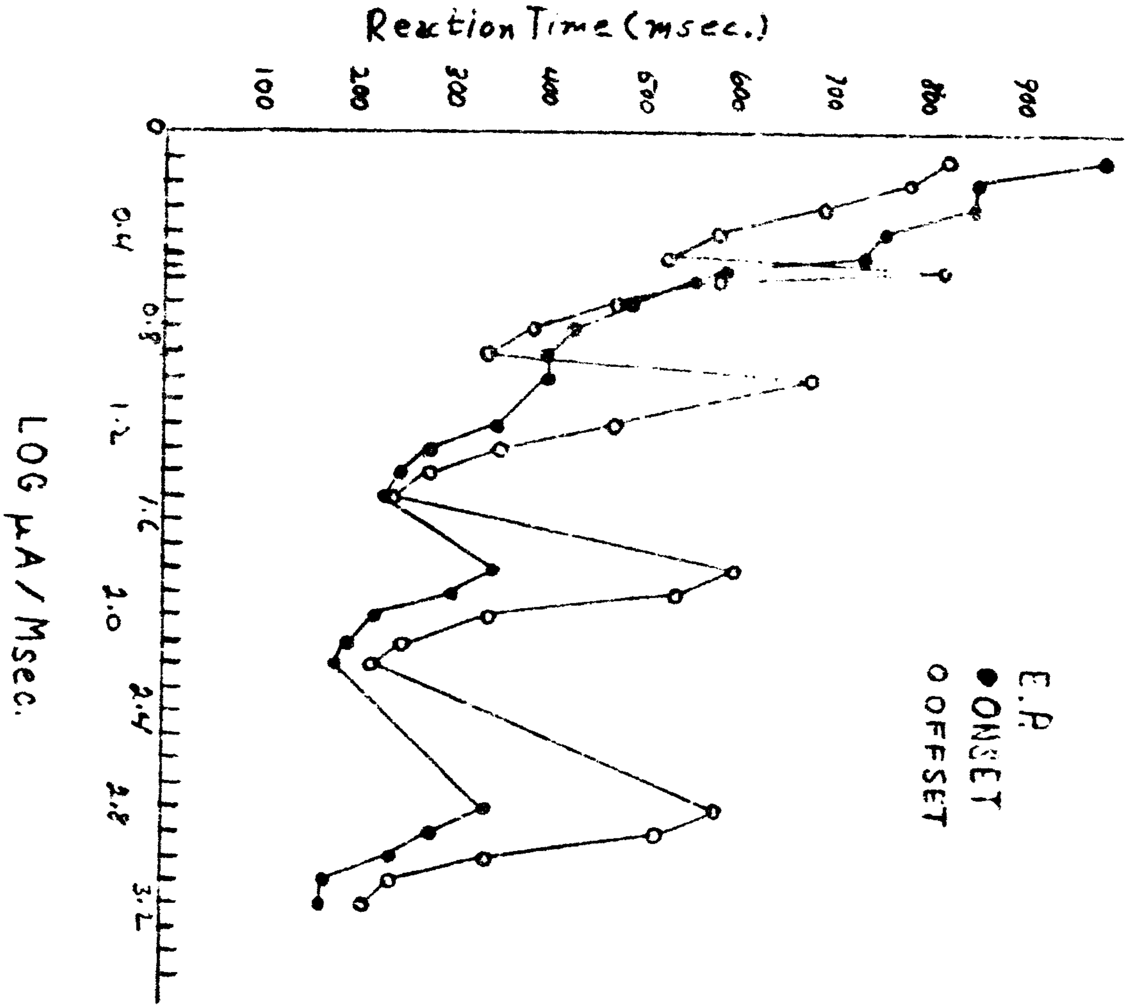

Reaction Time (msec.)
100
200
300
400
500
600
700
800
900
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
LOG μA/Msec.
E.P.
● ONSET
○ OFFSET

Fig. 2.1a

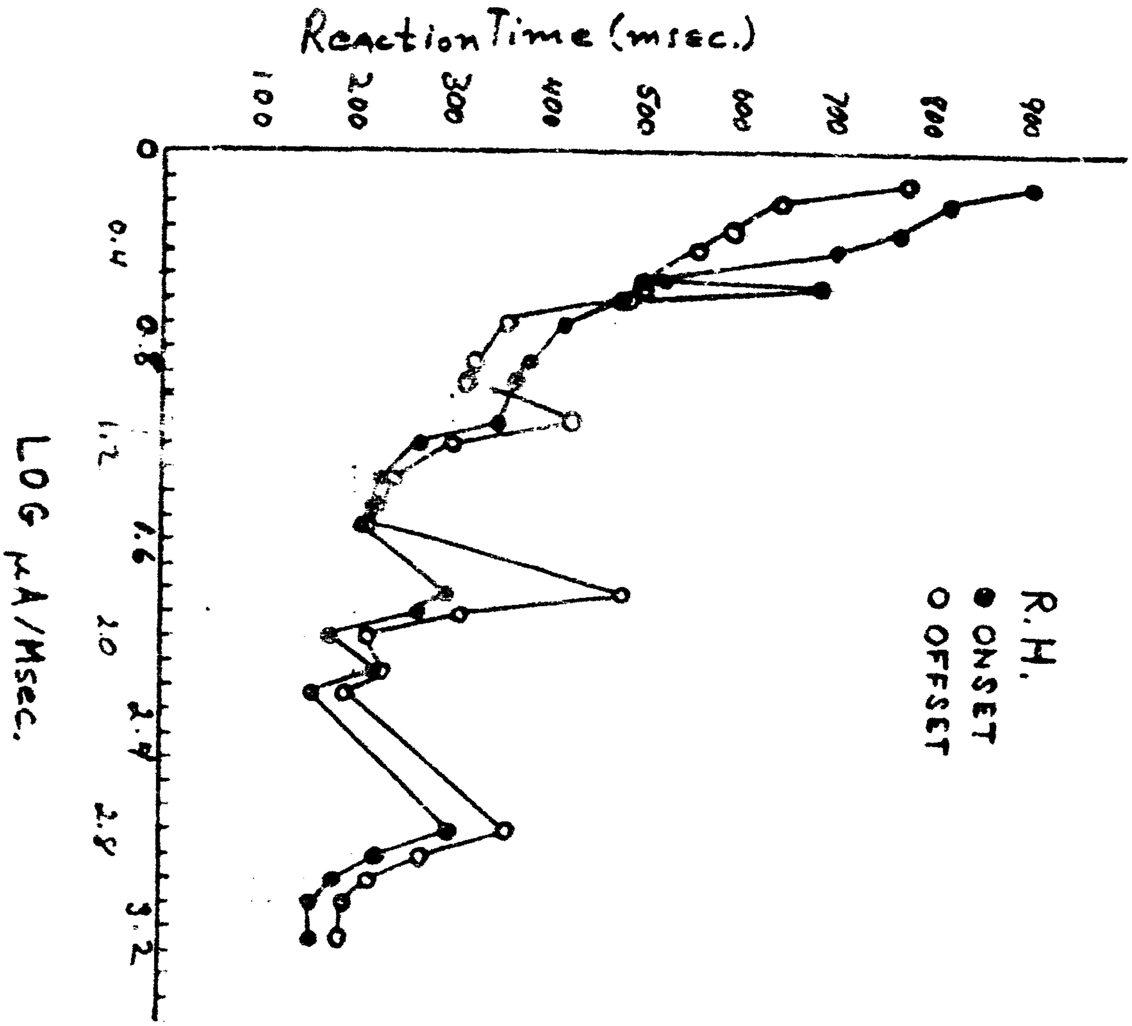

Reaction Time (msec.)
100
200
300
400
500
600
700
800
900
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
LOG μA/Msec.
R.H.
ONSET
OFFSET

Fig. 2.1a

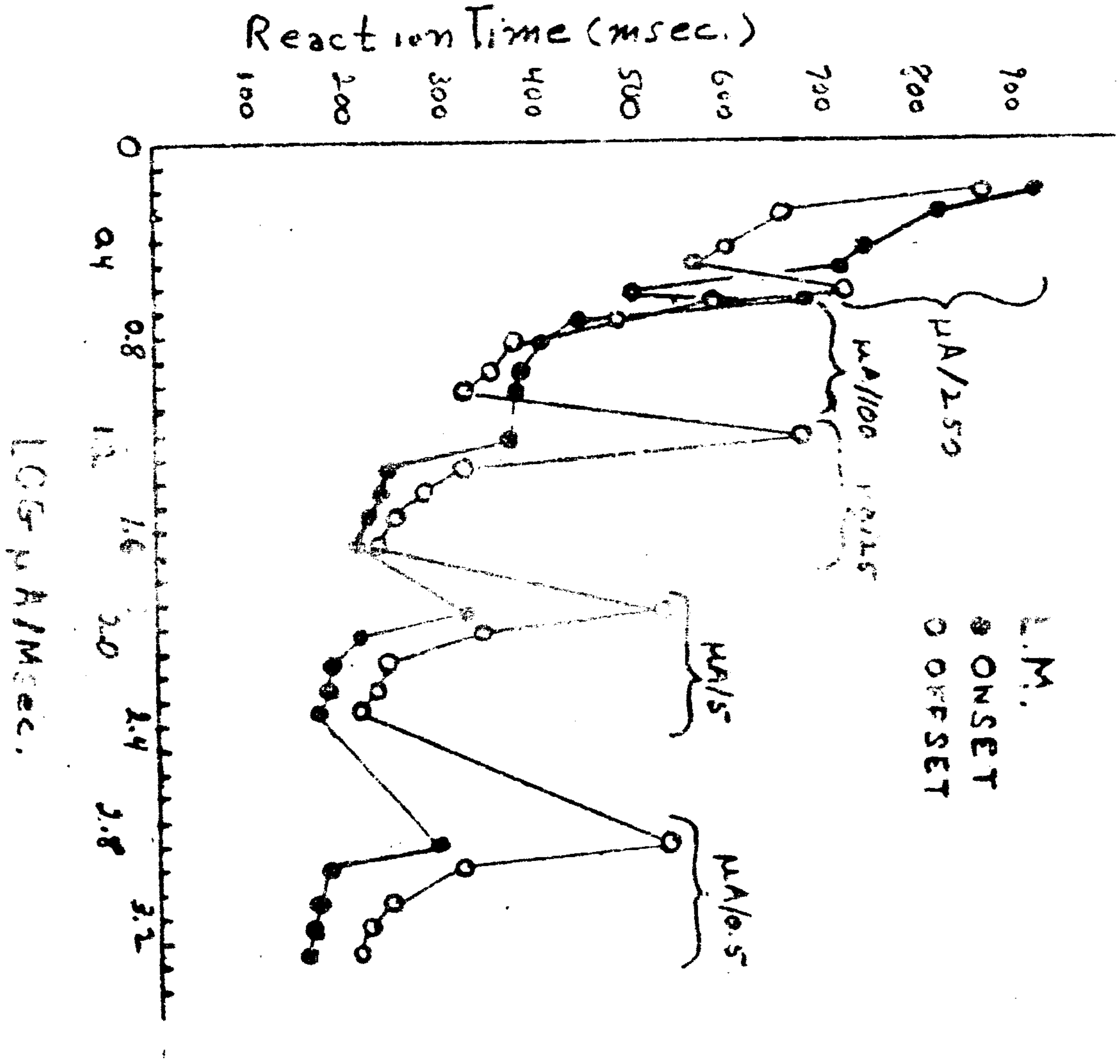
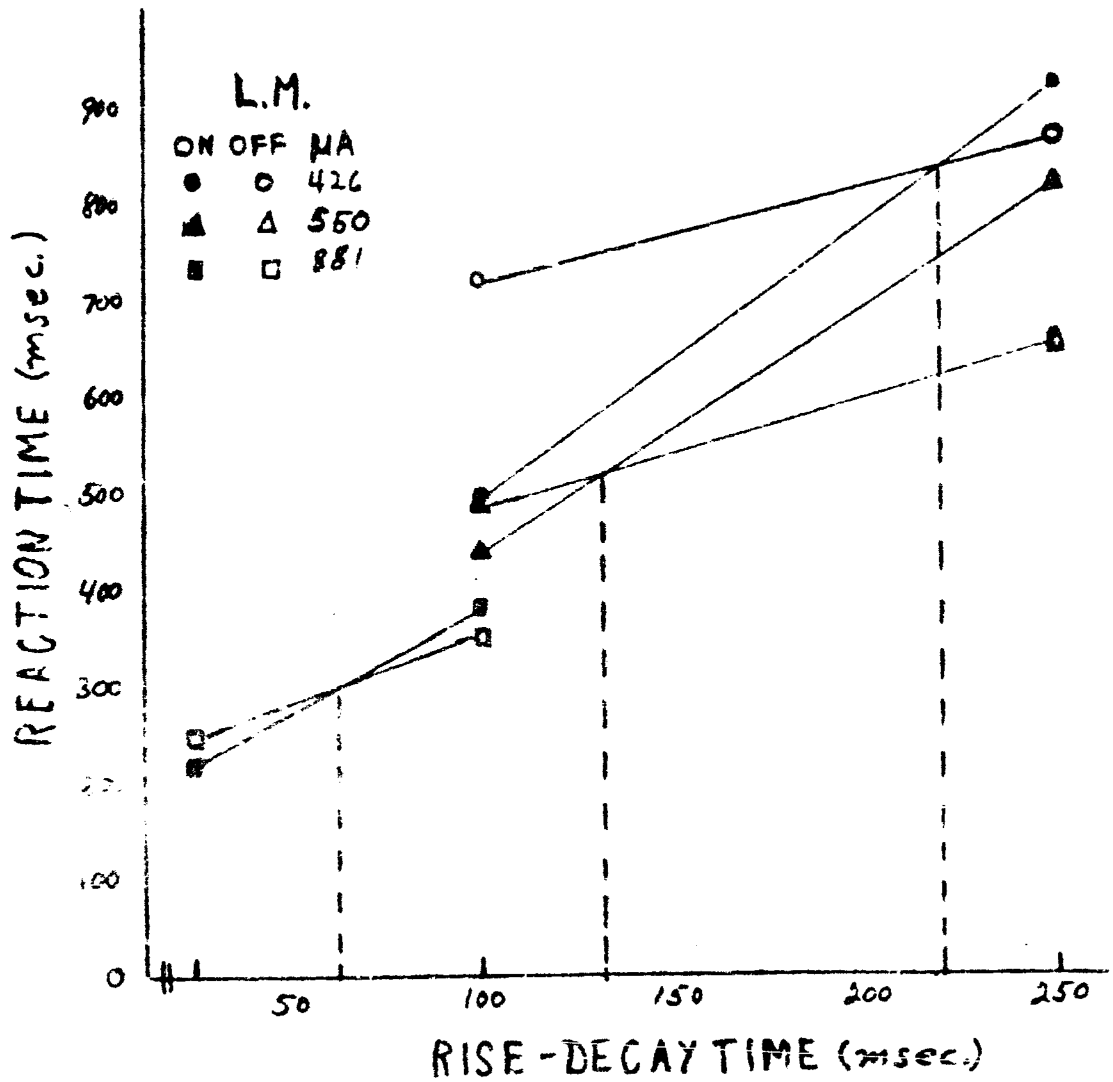

Reaction Time (msec.)
LOG µA/Msec.
L.M.
ONSET
OFFSET
µA/250
µA/100
µA/5
µA/0.5

Fig. 2.1c



L.M.
ON OFF μA
426
550
881
900
800
700
600
500
400
300
100
0
50
100
150
200
250
REACTION TIME (msec.)
RISE-DECAY TIME (msec.)

Fig. 2.2

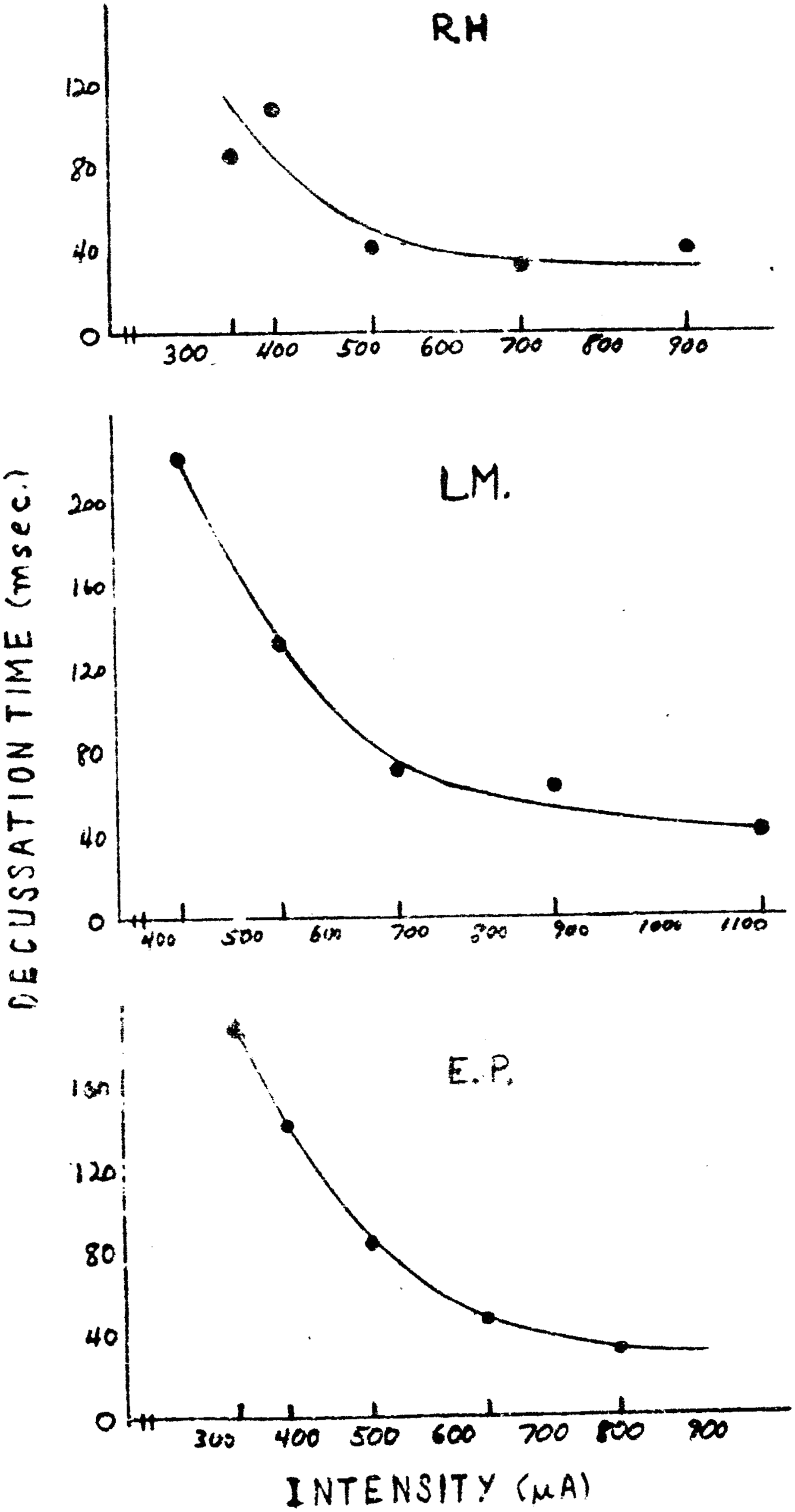


Fig. 2. 3